SPECIAL CONTRACT PROGRAMM **SPC 95-4028**

The United States Air Force European Office of Aerospace Research and Development - from JUL 1995 to JUL 1996

THE RESEARCH OF STRUCTURAL MODELS OF FATIGUE DAMAGE OF MIXTURE FILMS

(REPORT)

Principal Investigator - **Dr. Sezgir Shamirzaev**, Head of Semiconductors Films Gages Laboratory of Physical - Technical Institute, Scientific Association "Physics-Sun" Academy of Sciences of Uzbekistan .
G. Mavlyanova, 2-b; PTI of AS, Tashkent, 700084
Republic of Uzbekistan.
Tel/Fax (+7 3712) 35-40-32; (+7 3712) 35-42-91
Email : shamir@apc.org.glass

Шами!, Aug 5, 1996

(signature, date)

TASHKENT - 1996

Dr. S.Kh. Shamirzaev

NON PRSONAL CONSULTING SERVICES AS FOLLOWS:

UNAUTHORIZED CHANGE OF ITINERARY

F7LEOB51280500

0001	1	job	$12,000.00

Dr.Shamirzaev will perform a servise consisting of investigations in the research of strustural models of fatigue damage of mixture films. Develop mathematical moels connecting an electrical resistance change of semiconductor mixture films with the number of loading cycles. Research the damage mechanisms that are dictated by the mixture medium responce and sensitive element performance. Develop a fatigue damage model of semiconductor mixture films for irreversible random deformation. Develop principles to predict irreversible aerospase structural characteristics under mechanical loads. Payment will be made upon receipt and acceptance of abstract , due two weeks after award of contract.

0002	1	rpt	$12,980.00

Final payment to be paid upon receipt and acceptance of 5 copies of the final report describing the results of the work, due 60 days after end of contract.

(IAW JTR Vol.II) Report wil be submitted within 30 days upon completion of contract. The total amount of this order includes all report preparation costs. Payment will be made upon acceptance of the report.

Purchase of Miscellaneous Contractual Consulting Service
Method of Payment: NET 30 DAYS

SPECIAL PROJECT SPC-95-4028

THE RESEARCH OF STRUCTURAL MODELS OF FATIGUE DAMAGE OF MIXTURE FILMS

(Special Contract Program SPC 95-4028)

ABSTRACT. Fatigue damage of the industrial meterials are governed by the parameters of superim-posing on them a cyclic deformations. In order to evaluate these parameters the cumulative fatigue damage gauges (CFDGs) have to be used.

Fatigue damage of the materials could be inferred by the variation of the electric resistance (Δ R) of the sensitive elements (SE) of the CFDGs installed onto the industrial ele-ments, (for example, on aircraft fuselage).

Irreversible responses (Δ R[ε]) of SE from the superimposing cyclic deformation (ε) are bound to be far exceed the response (Δ R[T]) from attendant thermocyclic (T) process. SE of this sort CFDG are developed by us [1]. They are defined as films made of semiconductor mixtures (SMs). Films obtained by evaporation of Bi_2Te_3 - Sb_2Te_3 on to poliamide substrates. The films had variale volume contents of initial components. Some compositions provided high sensitivity to deformation. Weight of a single film is no more than 5 gram. Such films can be installed on a frame of aircraft. We hope to use these films for defense interests.

Under superimposing irreversible random (cycle) deformation, both an effective electric resistance - R_{eff} of the CFDG's SE and the microstructure in Sms as well as a microstructure of the industrial material are change.

The problem of the CFDGs development is to find the correlation between Δ R[ε] of SE and change in microstructure.

The existing procedure of analysis of durability of elements of an aircraft are based on account cycle loads at takeoff and landings, as well as on some known settled algorithms. The trouble with this procedures is lacking of the physical criterion of aircraft's reliability.

The correlation between R_{eff} of SMs and volume contents of initial components and form of their granular are given by us [1]. The model of fatigue damage of SMs films for regular loadings were first given also by us [1.2].

The propose of given project - to develope the mathematic models, connecting an electric resistance of SMs change with the number of loading cycles. We will research the damage mechanisms that are dictated by mixture medium response and SE performance. This project is aimed also at developing of fatigue damage model of SMs films for irreversible random deformation. The real processes of fatigue damage and their relaxation during rest, occurring in elements of aircraft at their operations, are

taking into account. This fatigue damage model will be used to develop principles to predict irreversible aerospace structural characteristics under mechanical loads.

Itis expected to receive the new knowledge about nature of formation of effective target parameters of SE. This information will be prepared for publication and used for development of new sensitive indicatos of fatigue damage.

TECHNICAL PROPOSAL. We extend synergetic concepts and their application for the determination of Sms states. When superimposing deformations the SE state changes. We describe it in the following way. Basing on the experimental data, to derive a "time series" (survival data) consisting of n terms. Analyzing the series, to establish it phase dimensionality andto carry out an adaptive prediction of the parameters composing a numerical value of the (n + 1)th term of the "time series". Then, basing on (n + 1) terms of the series, to predict a numerical value of the (n + 2)th term of the series, and so on. Ses are being monitored.. Research design and methods include the following item :

ITEM **DATE**	Nov 1995 I	Mar 1996 II	Iun 1996 III
1. SMs performance with variable volume contents of initial components	**I - 1**	**II - 1**	
2. Determination of obtained SE films composition		**II - 2**	
3. To bring out the initial elements of the SE films by X-RAY Fluorescence spectrometer (quality analysis)	**I - 3**	**II - 3**	
4. The advancement of the experimental arrangement for measurement of SEs resistances change under superimposing of the regular deformation with the various amplitude and degree of asymmetry.	**I - 4**		
5. The preparation of experimental data (time series) of successive effective resistance of SE.		**II - 5**	
6. Investigation of the SE structural models.	**I - 6**		**III - 6**
7. The development of the matematic models, connecting an electric resistance change of SMFs with the number of loading cycles.		**II - 7**	
8. The preparetion of the paper for publication and delivering report.		**II - 8**	
9. The development of a fatique damage of Sms films model for irreversible random deformation.		**II - 9**	
10.Discussion of the damage mechanisms that are dictated by mixture medium response and SE performance.			**III - 10**

EXPECTED RESULTS:

I-1. 11 group of samples from mixture **Bi_2Te_3 - Sb_2Te_3** with 0.1 volume contents of **Fe** apart.

I-3. Impurities of specific interest are occurs in initial mixtures

I-4. Experimental arrangement for measurement of SE's resistance

I-6. SE structural models.

II-1. SE films for investigations of structural models.

II-2. Some preliminary general conclusions from experimental observations.

II-3. Impurities are occurs in SE films.

II-5. Experimental data.

II-7. Mathematic models.

II-8. Reports.

II-9. Principles to predict irreversible aerospace structural characteristics under mecanical loads.

III-6. Impedance of SE film and its structures.

III-10. Internal friction of industrial materials. Abstract of investigations are in sight.

1. SMs performance with variable volume contents of initial components.

One can get SE for CFDGs using various technology. It may be evaporation of initial components in vacuum or its agitation, pressure ,and agglomeration in sealed quartz tubes. We are using both technology.

Two party containing 11 groups of SEs were perfomed. Initial components are **Bi_2Te_3-Sb_2Te_3** and **Fe**. An agitation granular sizes both of components were no more than 40 mkm. First party of SEs were prepared under the pressure $P = 3000$ kg/cm^2 . For the second party $P= 5000$ kg/cm^2. The length of the SE $L_1 = 1$ cm; the width $L_2 = 0.1$ cm , and the thickness $L_3 = 0.1$ cm.
Let $Y_1 = V_1 /(V_1 + V_2)$. V_1 - volume of **Fe** and V_2 - volume of **Bi_2Te_3 - Sb_2Te_3** . So Y_1 is volume contents of **Fe**. 11 group of SE had next amount of Y_1 : $Y_1 = 0.0; 0.1; 0.2; 0.3; 0.4; 0.5; 0.6; 0.7; 0.8; 0.9; 1.0$. For example, samples labeled as 0.3 - 3 and 0.3 - 5 have the same $Y_1 = 0.3$, but prepared under various pressure : $P_1 = 3000$ kg/cm^2 and $P_2 = 5000$ kg/cm^2. .Tables 1-3 contain the amount of effective electric resistivity R_{eff} of SEs for various situations. Tables 1-2 for superimposing of loading ($\pm \sigma$) cycles, and Table 3 for superimposing the thermocycles (± 60 C) processes. $+\sigma$ correspond to an extension strain ; $-\sigma$ correspond to a compressive strain.

Table 1

Y_1-P	03 - 3	04 - 3	05 - 3	07 - 3	07 - 3	08 - 3	08 - 3
	$\sigma = \pm 9.1$ kg/mm^2;	$\sigma = \pm 6.96$ kg/mm^2 ;	$\sigma = \pm 8.85$ kg/mm^2;	$\sigma = \pm 6.88$ kg/mm^2 ;	$\sigma = \pm 8.85$ kg/mm^2 ;	$\sigma = \pm 6.88$ kg/mm^2;	$\sigma = \pm 8.85$ kg/mm^2 ;
N_{load} - cycles	R*10^2 Ohm	R*10^2 Ohm	R*10^2 Ohm	R*10^2 Ohm	R*10^2 Ohm	R*10^2 Ohm	R* 10^2 Ohm
0*10^3	3.29	3.02	3.50	3.36	4.74	0.59	0.70
2*10^3	12.64	3.33	5.80	4.63	24.45	1.35	10.52
4*10^3	24.98	3.53	8.17	5.01	49.86	1.51	16.54
6*10^3	40.30	3.70	9.75	5.60	55.36	1.60	17.18
8*10^3	43.20	5.22	10.59	6.30	71.21	1.65	-
1*10^4	52.32	7.22	11.35	7.14	68.24	1.63	-
2*10^4	79.43	35.87	12.03	8.59	-	1.81	-

Table 2

Y_1 -P	03 - 5	03 - 5	03 - 5	03 - 5	0 - 5
	$\sigma = +9.1$ $\sigma = -9.1$ kg/mm^2;	$\sigma = +\ 7.50$ $\sigma = -\ 10.70$ kg/mm^2 ;	$\sigma = +\ 10.70$ $\sigma = -\ 7.50$ kg/mm^2;	$\sigma = +\ 12.80$ $\sigma = -\ 5.40$ kg/mm^2 ;	$\sigma = +\ 5.40$ $\sigma = -\ 12.80$ kg/mm^2 ;
N_{load} -cycles	R*10^2 Ohm	R*10^2 Ohm	R*10^2 Ohm	R*10^2 Ohm	R*10^2 Ohm
0*10^3	2.41	2.22	2.17	2.04	2.41
2*10^3	4.96	4.32	5.15	3.79	6.22
4*10^3	6.68	4.97	6.03	4.66	7.48
6*10^3	7.25	5.24	6.38	4.85	7.66
8*10^3	7.87	5.44	6.91	5.21	8.22
1*10^4	8.20	5.56	7.23	5.42	8.66
2*10^4	9.08	5.95	8.64	6.22	9.34

I-1. The SE samples, labeled as 03 - 5 are preferable for CFDG

II-1. The films were obtained by evaporation Bi_2Te_3 - Sb_2Te_3 onto a polyamide substrates. Under evaporation a chemical reactions (for example)

$$Bi_2Te_{3\,(solid)} \Leftrightarrow 2BiTe_{(gas)} + 1/2\ Te_{2\,(gas)} \quad \text{or}$$

$$Sb_2Te_{3\,(solid)} \Leftrightarrow 1/4Sb_{4\,(gas)} + SbTe_{(gas)} + Te_{2\,(gas)}\ ,$$

take place. The condensation processes also have some features. As a resalt film had a variable volume content of initial components and became heterogeneous.

Table 3

Y_1	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
N_{therm} cycles	$R10^3$ Ohm	$R10^3$ Ohm	$R10^3$ Ohm	$R10^3$ Ohm	$R10^3$ Ohm	$R10^3$ Ohm	$R10^3$ Ohm	$R10^3$ Ohm	$R10^3$ Ohm	$R10^3$ Ohm	$R10^3$ Ohm
0	118	44.7	42.7	31.6	29.9	29.0	45.1	35.4	22.8	59.5	48.9
153	117	41.6	39.6	30.9	32.3	29.3	46.3	37.1	23.9	67.1	58.7
332	117	44.7	42.8	32.0	32.2	29.5	46.4	37.2	24.0	68.2	59.8
437	118	45.3	43.3	34.5	32.2	29.5	46.7	37.9	24.4	69.1	62.3
560	118	45.2	43.3	47.1	32.1	29.6	46.0	38.0	24.3	69.2	62.5
680	118	45.8	43.4	45.5	32.5	29.6	46.6	38.1	24.4	69.6	62.9
690	117	45.2	43.5	55.3	33.9	29.7	47.2	39.0	25.2	73.3	65.9

Making some effort one obtain opportunity to prepare SE films suitable for CFDGs. Some compositions provided them with high sensitivity to deformation Figure 1 show the resistance - R_{eff} of films versus the number of superimposed cycles (n). Figure 1a for simple and Fig.1b for complicated modes of loading. For this SEs changes of R_{eff} are no more than 10% for superimposing 10^3 thermocycles (T = ±60C) process.

2. Determination of obtained SEs films composition

Figures 1-3 show resistance R_{eff} of semiconductor mixtures versus the vary type and number of syperimposed cycles (N) and n - number of measurements. There are a vary types of alternating strain for S-CFMs as well as 03-5 samples.
Complicated modes of loading (alternating [bending] strain) are superimposed on S-CMs . The sequence of operations of the loadings are changed (See Fig 7. And fig 9 in [2]) . It shows noncommutativity of the loadings operators.
Figure 3 shows the resistance R_{n+1} versus the resistance R_n .

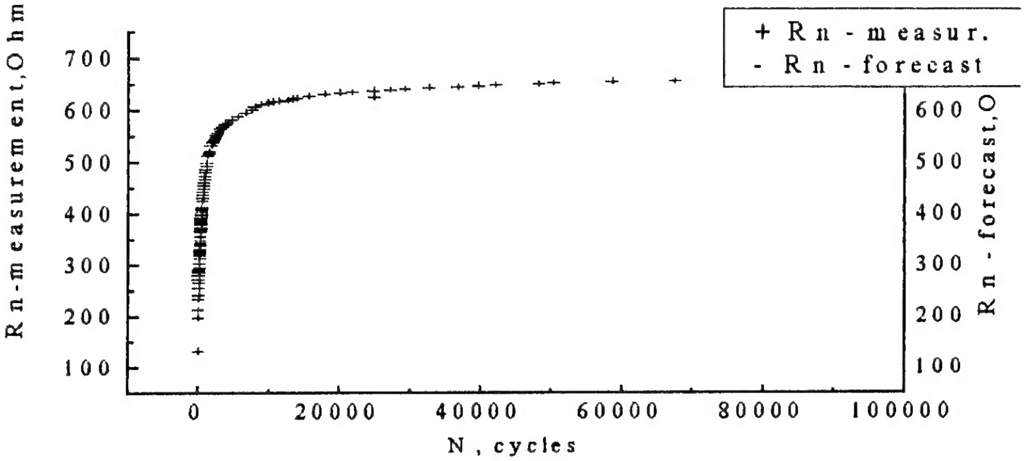


Fig 1a. HS-CFM's R_{eff} versus the number N cycles. Simple mode of loading (alternating [bending] strain}.

II-2. Some preliminary general conclusions from experimental observations.

Both, the growth number of superimposed cycles as well as random deformation have a result an "agitation" of electronic compositions of HS-CFMs. Such "agitation" accompanies with loss of the energy deformation and leads to irreversible change of the previous electronic configuration. So for a HS-CFMs the new factor appears - "history" of a sequence electronic compositions. In other words the HS-CFMs have a new factor - "historical" dimention. A fracture dynamic of HS-CFMs requires the sequence measurements of the R_n (**n** - is a number of a measurement).

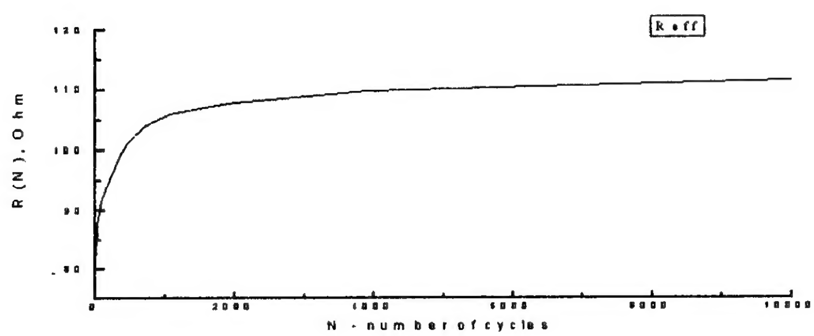


Fig. 1a$_1$. Sample - S-CMFs. Simple mode of loading (alternating [compressive-extension]strain)

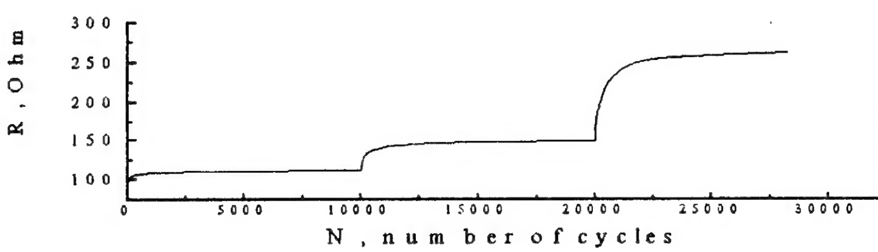


Fig. 1b. Sample - HS-CFMs. Comlicated modes of loading , (alternating [bending] strain)

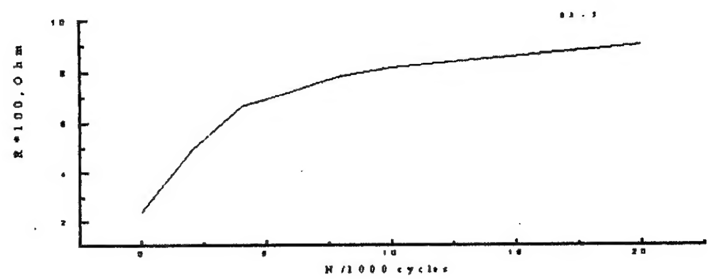


Fig. 1c. Sample 03-5 (Table.2). Simple mode of loading (alternating[bending] strain)

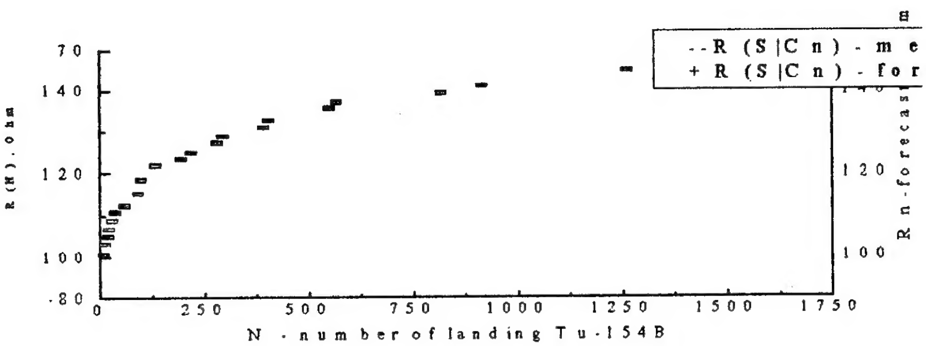


Fig. 1d. Sample - HS-CFMs. N - number of landing TU -154b.
(Wing spectr of loading)

II-2.1. Procedure of time transformation.

Let X - time be the time in cycles of loading : X = 0. 1, 2, 3, ... and this value is not proportional to chronological time. τ_1 - cronologocal time interval, corresponding to process of one cycle of loading.

Let T - time be chronological time measured in hours, days, minutes , etc., so T = 1, 2, 3, ... in corresponding units of time. Let T_0 - the period of "rest". So, $T = \tau_1 * X + T_0$.

Let Y - time be the time in landing of a plane : Y = 0, 1, 2, 3,...
τ_2 - chronological time interval, corresponding to process of taking off and landing of a plane.

Fig.2 Sample 03-5. Alternating [bending $\sigma_+ = +5.40$ kg/mm^2; $\sigma_- = -12.80$ kg/ mm^2] strain ; n - number of measurement (Tab 3)

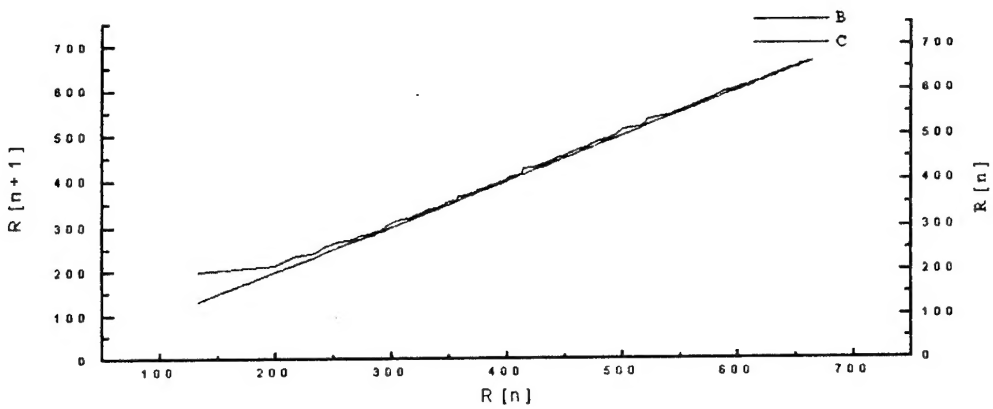


Fig.3a The R[n+1] versus the R[n] ; n - number of measuremrnt.
Sample HS-CFMs. Simple mode loads (alternating [compressive - extension ($\sigma_\pm = \pm 25$ kg/mm^2)] strain)

If loading cycles duration varies at random as it occurs, for example, at the aircraft flights, it is desirable to be able to convert damages accucumulation in T - time and inversely.

It can be done with the help of " time-transmission" function $Y = G(X)$ [3].

In the simple case ($T_0 = 0$) $T = \tau_1 * X = \tau_2 * Y$, take place, and so :

$$Y = \gamma_{1,2} * X, \text{ where } \gamma_{1,2} = \tau_1 / \tau_2 .$$

Let $X = \alpha_1 ; \alpha_2; \alpha_3 ; \alpha_4 ;..... \alpha_n ; ....$ Then for $R_{eff}(X)$

$R_1 = R_{eff}(\alpha_1)$; $R_2 = R_{eff}(\alpha_2)$; $R_3 = R_{eff}(\alpha_3)$;.... ; $R_n = R_{eff}(\alpha_n)$; .... , take place. For the same fatigue damage $R_{eff}(X) = R_{eff}(Y)$ take place. As a result one have:

$X =$	α_1	α_2	α_3	.	.	.	α_n	.	.
$R_{eff} =$	R_1	R_2	R_3	.	.	.	R_n	.	.
$Y =$	$\gamma_{1,2}*\alpha_1$	$\gamma_{1,2}*\alpha_2$	$\gamma_{1,2}*\alpha_3$	.	.	.	$\gamma_{1,2}*\alpha_n$	.	.

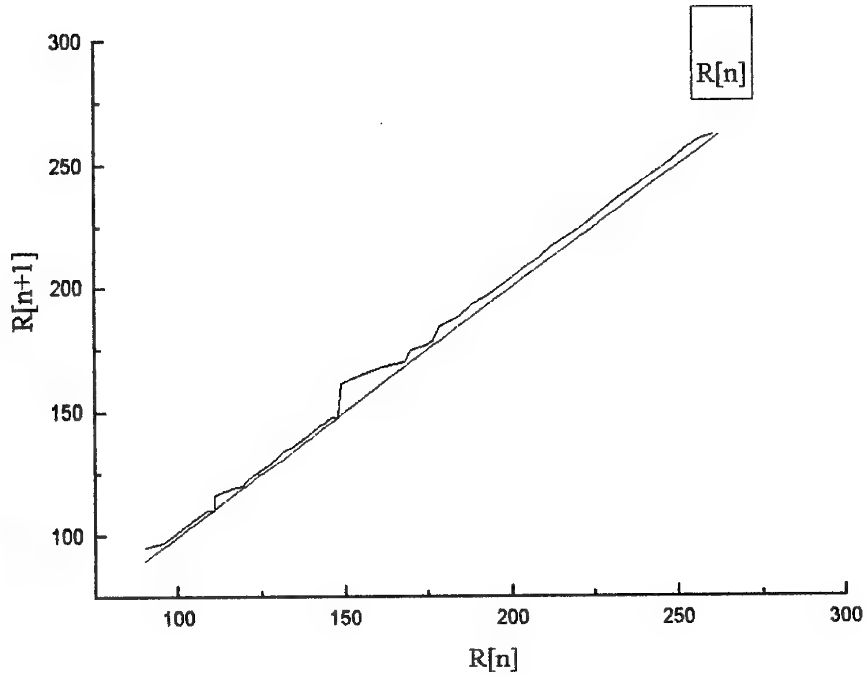


Fig.3b . **The R[n+1] versus the R[n] ; n - number of measuremrnt**
Sample HS-CFMs. Complex mode loads (alternating [compressive - extension] strain) one after another:
$\sigma_{\pm} = \pm 15$ kg/mm^2 ;$\sigma_{\pm} = \pm 20$ kg/mm^2 ;$\sigma_{\pm} = \pm 25$ kg/mm^2

In the case $T_0 \neq 0$ the relationship $Y = \gamma_{1,2} * X + (T_0 / \tau_2)$, take place

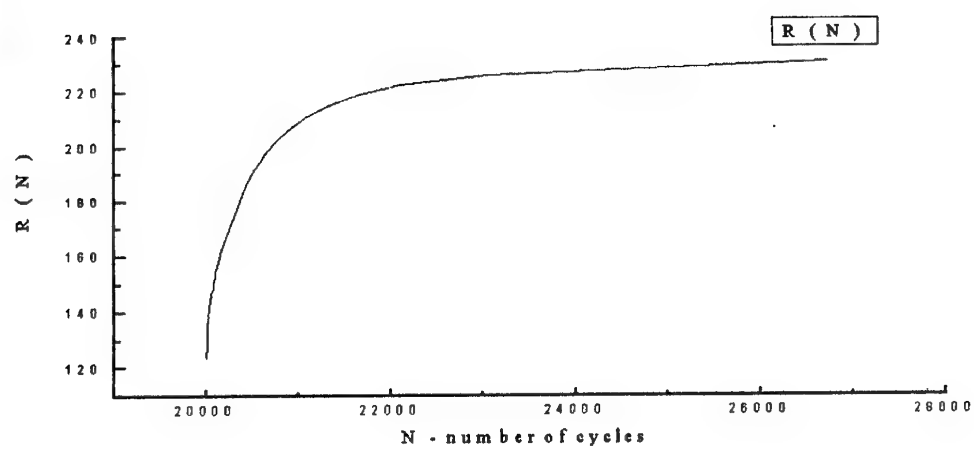


Fig.4 a R_{eff} versus the N - number of cycles

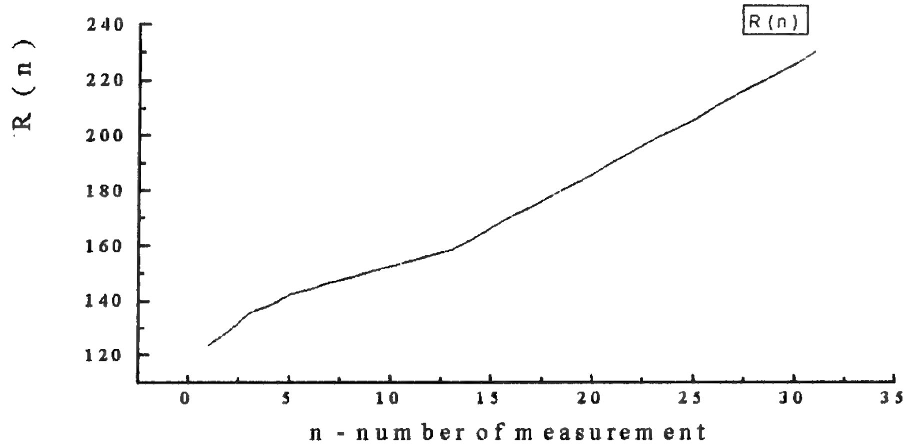


Fig.4 b R_{eff} versus the n - number of measurement

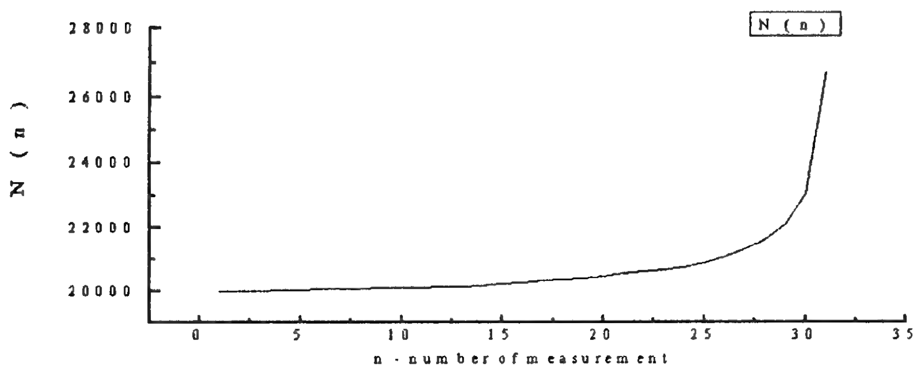


Fig.4 c Number of cycles - N versus the n - number of measurement

The use of break of G(X) or break of its derivation gives one the possibility to take into account the periods of "rest", damages accumulation in the time of testing, effect of random overloading, influences of sharp enviromental changes in the aircraft operation process.

Figure 4 show the time transformation procedure. More information one can find in (**II-8** [7]).

3. To bring out the initial elements of the SE films by X-RAY Fluorescence spectrometer (quality analysis)

There are exist some elements (materials) which can be used for preparing CFDGs. The simplest model of high sensitivity of HS-CFMs is given bellow. Impurity of **La**, and similar ($M_{eff} / M_0 << 1$) the number of elements, are exist in typical of HS-CFMs. They can be measured by X -RAY fluorescence spectrometer.

/

I-3. Impurities of specific interest are occurs in initial mixtures

Table 4 shows the fluorescence spectrum line elicited from analyse of initial mixtures.

Table 4

λ 10^{-11}cm	929	942	1144	1314	1334	1392	1418	1432
I Imp/sec	108	111	18699	1548	294	921	450	830
Corresponding element	Cd 930.66 KB2	Sb 940.71 KA1	Bi 1143.86 LA1	Bi 1316.10 L1	Nb 1331.52 KB1,3	Cu 1392.22 KB1,3	Mo 1418.60 KA1	Re 1432.90 LA1
λ 10^{-11}cm	1490	1540	2284	2408	2568	2776	3077	3031
I Imp/sec	733	1573	163	28	79.5	41.8	162	306
Corresponding element	Nb KA1	Cu 1540.56 KA	V 2284.40 KB1,3	La 2410.50 LB3	Ba 2568.21 LB1	Ba 2775.95 LA1	Te 3076.80 LB1	Sc 3030.9 KA

II-3. Impurities are occurs in SE films.

Table 5 shows the fluorescence spectrum line elicited from analyse of the semiconductor film mixtures. There are exist next elements lines added to Table 4 :

Table 5

λ 10^{-11}cm	764	784	792	812	828	876	940
I Imp/sec	4504	3267	2992	2523	1878	3842	7094
Corresponding element	Th 765.21 LB1	Sr 782.92 KB1,3	Th 792.57 LB4	Bi 813.11 LG1	Y 828.84 KA	Sr 875.26 KA	Bi 938.55 LB3
λ 10^{-11}cm	956	968	976	1104	1140	1156	1312
I Imp/sec	8572	4569	2507	874	10254	6257	886
Corresponding element	Bi 955.18 LB2,15	Th 967.88 LA2	Bi 976.90 LB4	Se 1104.77 KA	Ir 1140.85 LB3	Bi 1155.36 LA2	Pt 1313.04 LA1

4. The advancement of the experimental arrangement for measurement of SEs resistances change under superimposing of the regular deformation with the various amplitude and degree of asymmetry.

I-4. Experimental arrangement for measurement of SE's resistance.

Description of device for measurement changes of resistance of heterogeneous materials during imposing of deformation.

The device is intended for measurement changes of resistance R_{eff} of heterogeneous materials (HMs) during superimposed the cyclic deformation on them . The device is constructed on the base of device described in [2,4]. The block diagram of device is given on fig. 5.

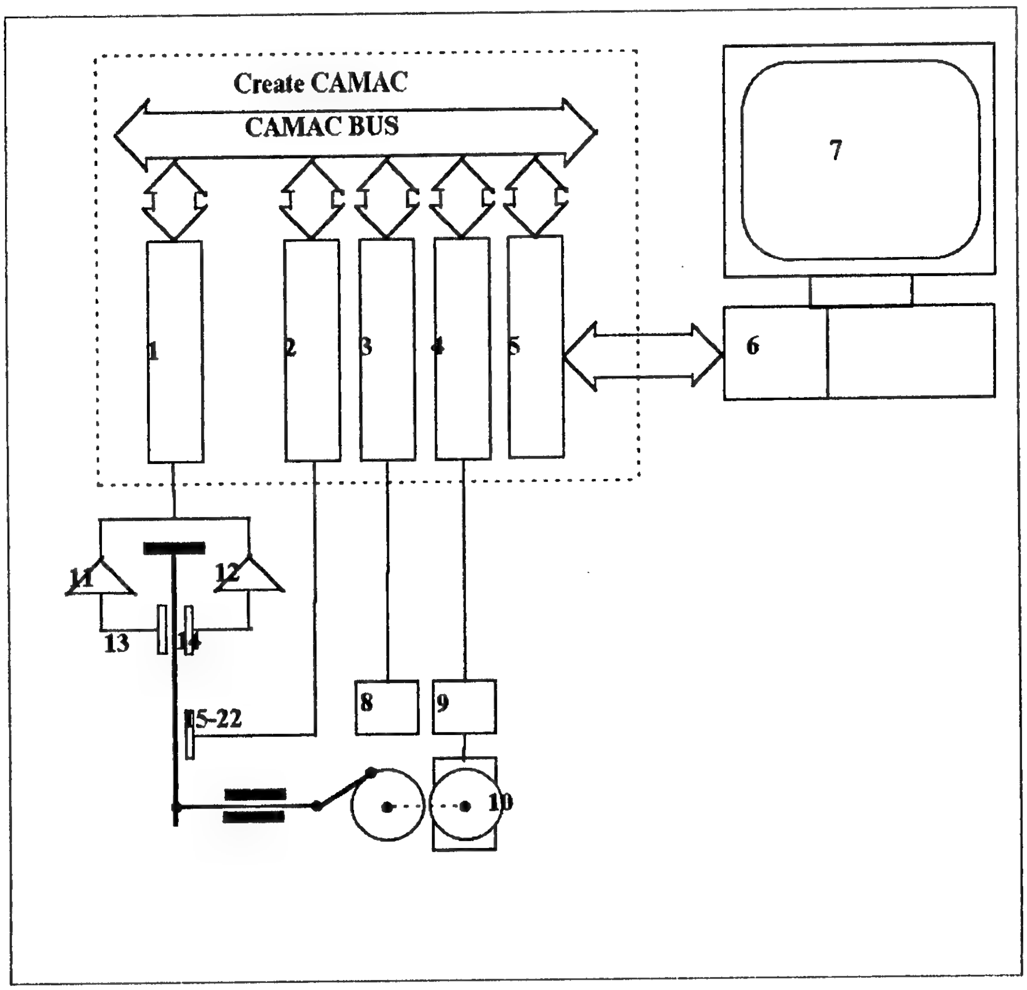


Fig. 5 - Module 4 ADC10, 2 - Module 32 ADC14, 3 - ADC, 4 - Target register, 5 - Creat Controller, 6 - Adapter CAMAC, 7 - IBM PC Computer, 8 - Detector of revolutions, 9 - Control block engine, 10 - Engine, 11-12 - Amplifier, 13 - HM's detector, 14 - Tenzo-detector, 15-22 - HM's detectors

For measurement changes of the HM's resistance 4-channel bipolar 10-digit ADC (4ADC10) is used. It posseses the following characteristics:

- A level of source signals + / -10 . Entrances have protection from overstrain.
- Source impedance on entrances not less than 100 Kohm.
- Frequency of a sine wave source signal by amplitude 10 V: no more 300 Hz.
- Speed of increase of a source signal: not more than 20 mV/mks.
- Accuracy of transformation: not more of 0.1 %.

The module permits to read out data from source voltage on each channel in any moment of a time, i.e. each ADC "watches" the source signal and continuously produces a code, appropriate to source voltage. There is an opportunity " to freeze" data on a source voltage at all 4 channels and to measure values on all four channels. The command "to unfreeze" (start-up) of ADC transfers them in tracking mode and through a time not more than 1 ms the module is ready for the issue of information on a CAMAC BUS.

For allocation changes R_{eff} at measurement of dynamic characteristics HM a device of automatic compensation constant part is intended.

The function chart of a system of automatic compensation is indicated on Fig. 5a.

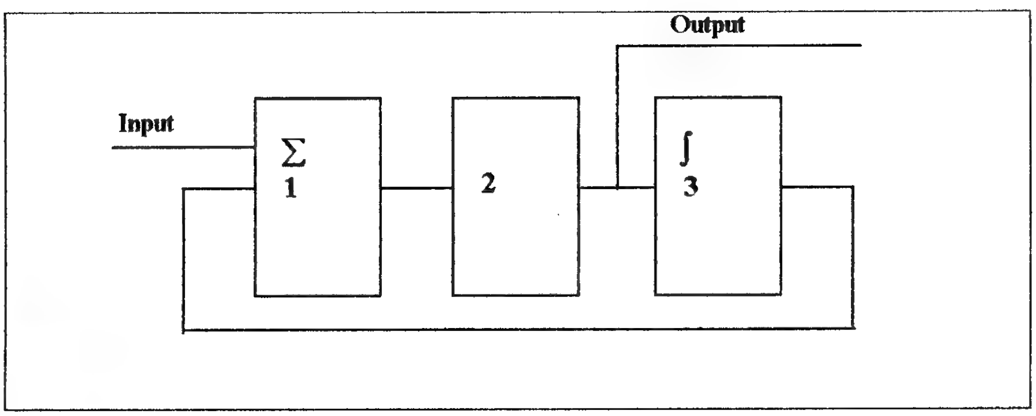


Fig.5a. 1 - Adder, 2 - Amplifier, 3 - Integrator.

Signal from the HM detector passing through adder 1 and the amplifier 2 causes occurrence of a signal on output of device and input of integrator 3. The signal on output of integrator is opposite to polarity source.

The certain time later a signal from output of integrator completely compensates a signal from the HM detector and on output the signal will be equal zero. At superimposing of cyclic deformation , a signal from the HM detector has variable part, which is carried out through the adder 1 and the amplifier 2 will act on ADC and input of integrator 3.

On output of integrator the signal will not change, since integral from variable part is equal zero and the device as a whole behaves as a usual amplifier. The signal from a tenzo-detector through a usual amplifier acts on a channel

14ADC10. With the help of the roll-in from the tenzo-detector "zero" (non-loaded) position of a beam is supervised.

For measurement of residual resistance of HM detector the standard noiseproof 32 channel 14-digit ADC (ADC14) is used. The ADC14 provides transformation of electrical resistance to 16 channels over 3-wire circuit. ADC14 provides measurement of electrical resistance from 0 up to 5 Kohm and provides automatic switching subranges - 5000, 500 and 50 Ohm with accuracy 1, 0.1 and 0.01 Ohm. A digital code of result transformation has 13 digit. The time of transformation is not more than 100 ms.

For setup of the number of cycles deformations and synchronization of measurement changes of the resistance HM the number of revolutions detector is used. The process of measurement of signals from the HM detector and tenzo-detector begins at the moment of occurrence of a pulse with detector number of revolutions, which acts on an input of the L-query standard DAC and finishes at the moment of the next pulse occurrence.

The start and stop of a electric engine is executed with the help of the target register.

For management of device the personal computer IBM PC with MS-DOS is used. For connection a controller CAMAC to IBM PC the special 8-digit interface is used, which is inserted in free slot of IBM PC motherboard.

For management of experiment a special graphic Windows-like environment,is written ,which provides:

- Measurement changes of resistance from one HM detector and one tenzo-detector during one cycle of imposing deformation.
- The first 5 coefficients of Furie-decomposition calculation.
- These curves viev on a display.
- Measurement of residual resistance HM till 8-channels.
- Preservation and loading of data files.
- Quantity setup of deformations and time cycles.
- Zero setup of amplifiers of signals from detectors.
- "Zero" (non-loaded) position of a beam control.

After installation of zero position of a beam residual resistance of HM detector are measured data which are stored in a file.

The process of measurement consists of following stages:

- Electric engine is started.

- The detector of number of revolutions counts the certain quantity of signal cycles from the HM detector. After that the tenzo detecor reads data during one period of deformation.
- The engine stops.
- The setting endurance of the time for relaxation of the HM detector is made.
- The measurement of residual resistance from HM detectors is made.

All measured data are automatically recorded in a file in ASCII code.

5. The preparation of experimental data (time series) of successive effective resistance (R_{eff}) of SE.

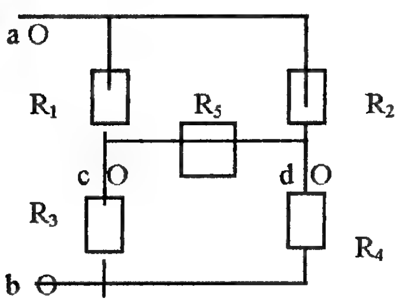
II-5. Experimental data were used for charts and tables.

6. Investigation of the SE structural models.

I-6. SE structural models.

It has been known [8], that resistance R_{eff} of HS-CFMs is simulated by lattice at the corner of which randomly located resistances - R_i (I = 1, 2, 3, ..., M ; M - total number of grains of HS-CFMs) R_i is the resistance of the grains of the HS-CFMs randomly connected with neighboring grains. In that model lattice one may find a simple module in Fig 6 . Model lattice consists of L modules, of this kind, each having index - k (k = 1, 2, ... , L).

$$R_{eff} = R_\alpha * (1 + R_5 / R_\beta) / (1 + R_5 / R_\gamma)$$



Where

$$R_\alpha = [R_1 * R_2 / (R_1 + R_2) + R_3 * R_4 / (R_3 + R_4)],$$

$$R_\beta = [R_1 * R_3 / (R_1 + R_3) + R_2 * R_4 / (R_2 + R_4)],$$

$$R_\gamma = [(R_1 + R_2) * (R_3 + R_4) + (R_1 + R_2 + R_3 + R_4)],$$

Fig .6 R_{eff} = R (a-b) - resistance of module measered from point **a** to point **b**

To gain a greater insight into why the R_{eff} - N dependance has the form given in Fig.1, assume that for every module kin to Fig.6

$$\Delta R_k(\sigma, m; N) = \begin{cases} G(\sigma, m)*N & \text{for } N \le N_k, \\ G(\sigma, m)*N_k & \text{for } N \ge N_k, \end{cases} \qquad (1)$$

takes place; N_k vary in quantity.

A scale factor - $G(\sigma, m)$ is the same for each module of the HS-CFM and depend on the amplitude - σ and degree of asymmetry - m of the superimposed regular cyclic deformation.

Each module will be able to contribute to the ΔR_{eff} accordance with statistic $g(k,\sigma)$:

$$\Delta R_{eff} = \Delta R(\sigma, m; N) = \sum_{k=1}^{L} [\, g(k,\sigma) * \Delta R_k(\sigma, m; N)\,];$$

$$\sum_{k=1}^{L} g(k,\sigma) = 1. \qquad (2)$$

$\Delta R_k(\sigma, m; N)$ - variation of resistance of a k - th module depend on the amplitude - σ and degree of asymmetry - m of the superimposed regular cyclic deformation. N is number of cycles.

For the sake of convenience, assume that $\Delta R_{max}(\sigma, m; N) = M(\sigma,m)$;

$$Z_k = G((\sigma, m)*N / M(\sigma,m); \quad (k = 1, 2, 3, ..., L). \qquad (3)$$

Z_k and $g(k,\sigma)$ can be found from experimental data, Fig. 1 , and formula (2). Proceed as follows :

$$\Delta R(N) = G*N*\sum_{k=1}^{L} g(k,\sigma) = G*N \qquad 0 \le N \le N_1$$

$$\Delta R(N) = G*N_1*g(1) + G*N*\{1 - g(1)\} \qquad N_1 \le N \le N_2$$

$$\Delta R(N) = G*N_1*g(1) + G*N_2*g(2) + G*N*\{1 - g(1) - g(2)\}; \quad N_1 \le N \le N_2$$

....

....

$$\Delta R(N) = G*\sum_{k=1}^{L} [N_k * g(k)] \qquad N_L \le N \qquad (4)$$

Notice, that $N_1 < N_2 < N_3 < ... < N_L$ and N vary in each of interval of $[N_k, N_{k+1}]$.

Let us take a derivative of $\Delta R(N)$ with respect to N in each of (4) equalities :

$$d[\Delta R(N)]/dN = G, \qquad 0 \le N \le N_1$$

$$d[\Delta R(N)]/dN = G^*\{1 - g(1)\} \qquad N_1 \le N \le N_1$$

$$d[\Delta R(N)]/dN = G^*\{1 - g(1) - g(2)\} \qquad N_2 \le N \le N_3$$

.... (4')

Then each subsequent equality can be subtracted from the preceding one. As a result one find all quantities of $g(k;\sigma)$, N_k, as well as $G(\sigma;m)$ and $M(\sigma;m)$ (See Figures in [2]) This model admits control of the structure mutations in HS-CMFs after N cycles of a superimposed regular deformation.

III-6. Impedance of SE film and its structures.

Table 6 and Table 7 show the resistance R(f) and capacity C(f) of HS-CFMs versus the deformation - ε ; f - frequancy of measurement.

Table 6

numb f Gz	0, R_{eff} Ohm	.1 R_{eff} Ohm	.2 R_{eff} Ohm	.3 R_{eff} Ohm	.4 R_{eff} Ohm	.5 R_{eff} Ohm	.6 R_{eff} Ohm	.7 R_{eff} Ohm	.8 R_{eff} Ohm	.9 R_{eff} Ohm	1,0 R_{eff} Ohm
300	65.10	65.30	65.40	65.40	65.40	65.40	65.40	65.40	65.40	65.40	65.40
400	64.90	65.10	65.20	65.30	65.40	65.40	65.50	65.50	65.50	65.50	65.50
500	64.70	64.90	65.10	65.30	65.40	65.50	65.50	65.60	65.60	65.60	65.60
800	64.00	64.30	64.60	65.00	65.30	65.60	65.70	65.80	65.90	65.90	66.00
900	63.80	64.20	64.40	65.00	65.20	65.60	65.70	65.90	65.90	66.00	66.00
1000	64.00	64.30	64.50	65.00	65.20	65.50	65.60	65.60	65.70	65.70	65.80
1100	63.94	64.23	64.47	64.84	65.05	65.32	65.44	65.52	65.53	65.54	65.57
1200	64.02	64.34	64.59	65.01	65.25	65.57	65.71	65.84	65.85	65.87	65.89
1300	63.86	64.23	64.52	65.00	65.24	65.57	65.70	65.84	65.88	65.92	65.99
1400	63.72	64.12	64.43	64.98	65.30	65.72	65.89	66.02	66.02	66.01	66.02
1500	63.62	63.91	64.16	64.63	64.92	65.26	65.38	65.53	65.60	65.71	65.83
2000	62.48	62.86	63.21	64.01	64.51	65.08	65.28	65.48	65.55	65.66	65.80
3000	61.82	62.29	62.74	63.74	64.36	65.07	65.33	65.61	65.69	65.7	65.86
10000	61.98	63.70	64.94	65.07	64.89	64.83	65.13	65.42	65.50	65.49	65.47
13000	62.08	62.52	62.91	63.77	64.29	64.89	65.20	65.52	65.59	65.53	65.44
$\varepsilon*10^3$	.000	.615	.718	.820	.923	1.025	1.138	1.230	1.333	1.435	1.537

Table 7

numb f Gz	0 C10⁷ F	.1 C10⁷ F	.2 C10⁷ F	.3 C10⁷ F	.4 C10⁷ F	.5 C10⁷ F	.6 C10⁷ F	.7 C10⁷ F	.8 C10⁷ F	.9 C10⁷ F	1.0 C10⁷ F
300	8.00	8.00	7.00	6.00	6.00	6.00	6.00	5.00	4.00	4.00	3.00
400	4.00	4.00	4.00	3.00	3.00	3.00	3.00	3.00	2.00	2.00	1.00
500	3.00	3.00	3.00	2.00	2.00	2.00	2.00	2.00	2.00	1.00	.800
800	2.20	2.20	2.20	1.20	1.20	.920	.800	.700	.600	.480	.300
900	2.00	2.00	2.00	1.10	.900	.790	.760	.690	.500	.470	.200
1000	1.20	1.20	1.20	1.05	.852	.782	.752	.670	.500	.460	.360
1100	1.147	1.137	1.092	.949	.844	.774	.742	.668	.567	.450	.346
1200	.986	.977	.927	.775	.665	.599	.582	.534	.461	.356	.249
1300	.959	.934	.874	.732	.620	.565	.556	.523	.443	.339	.234
1400	.829	.827	.785	.649	.550	.493	.478	.432	.359	.264	.174
1500	.800	.775	.720	.554	.441	.347	.313	.269	.228	.167	.095
2000	.523	.532	.501	.402	.324	.263	.239	.211	.181	.148	.117
3000	.378	.343	.307	.234	.206	.186	.192	.180	.162	.126	.085
10000	.147	.146	.142	.125	.108	.100	.115	.126	.124	.099	.070
13000	.125	.129	.130	.134	.138	.149	.146	.136	.116	.097	.078
$\varepsilon*10^3$	.000	.615	.718	.820	.923	1.025	1.138	1.230	1.333	1.435	1.537

7. The development of the matematic models, connecting an electric resistance change of SMFs with the number of loading cycles.

II-7. Mathematic models is described just below (II-8).

8. The preparetion of the paper for publication and delivering report.
The reports was sent to aviation materials conferense (Mar. 1996,, Moscow) and ADPC '96 (Dayton)

II-8. Report.

ADAPTIVE FORECASTING OF FATIGUE DAMAGE OF AVIATION DESIGNS WITH HELP HS-CFM

SEZGIR SHAMIRZAEV

Abstract

The researches of adaptive forecasting of efective electrical resistance (R_{eff}) of heterogeneous semi-conductorm film mixes (HS-CFMs) are introduced. HS-CFMs are rigidly installed on elements of an aviation design. On loading irreversible random (cycle) deformation changes occure in the R_{eff}, microstructure of HS-CFMs and microstructure of the aviation design material (ADM). The variations R_{eff} correspond to number N_{sum} of acoustic emission originated in ADM. The simplest model of high sensitivity of HS-CFMs is given.

The superimposed deformation and allied HS-CFM's microstructure are the stimulus element (SE) of set S. The active subset C of SE's of set S forms variability of R_{eff} at superimposed chaotic deformation. The existence of a couple of uncrossing subset **A** and **B** is found. In HS-CFMs researched it is established, that after each damage process all SEs of subset **A** become active, and all SEs of subset **B** - on the contrary become non active. The characteristics of subsets **A** and **B** as well as complex dynamics of their change with growth of number of superimposed deformation cycles were determined.

Experimental data array is considered as a "time series". Synergrtic methods are used. Applicability of the formulas described in paper for spectra of Tu-154 plane wing load is shown.

I. Introduction

Fatigue damage of aviation designs is governed by the parameters cyclic deformations superimposed on them. In order to evaluate these parameters, heterogenuos semi-conductor film mixes (HS-CFM) have to be used [1].

Fatigue damage of materials could be inferred from variations of the effective electric resistance (ΔR_{eff}) of the HS-CFM rigidly installed on elements of aviation design.

An irreversible reaction(R_{eff}) of HS-CFM to the superimposed cyclic deformation must considerably exceed the reaction (R_{eff}) to the attendant thermocyclic process. HS-CFM's of this sort are briefly outlined in [1]. Films were obtained by evaporation of Bi_2Te_3 - Sb_2Te_3 on to polyamide substrates.

The problem on the development of cumulative fatigue damage gages (CFDGs) is to find a correlation between ΔR_{eff} of HS-CFM and change in microstructures [2]. The structure models of the construction materials are given in [3,4]. The correlation between R_{eff} of HS-CFMs and volume contents of initial components and form of its granules are given in [15]. The model of fatigue damage of HS-CFMs films for regular loading were first given in [2].

The problem on the adaptive forecasting of fatigue damage of aviation designs is to determine the base of irreversible changes of HS-CFM's electron subset under superimposed deformation. This paper is aimed at developing of the base model of adaptive forecasting of changed occuring in the effective electric resistance (R_{eff}) of the HS-CFMs for irreversible random deformation.

Figure 1 shows R_{eff} versus the number **N** of loading cycles. This is typical of

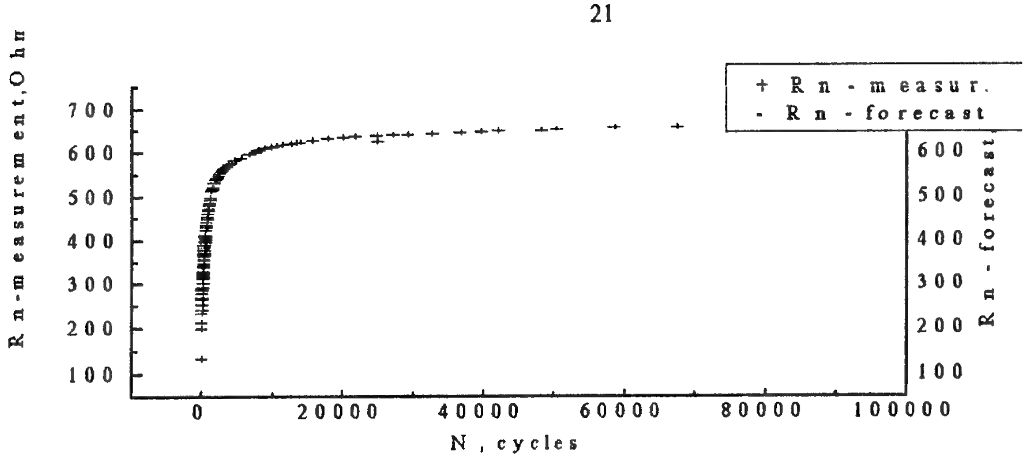


Fig 1. HS-CFM's R_{eff} versus the number N cycles

the heterogeneous semiconductor films for simple modes of deformation . Under irreversible random deformation , R_{eff} - n dependence became more intricate. A correlation between these situations is discussed below.

II. The simplest model of high sensitivity of HS-CFM

As an illustration, effective masses of electrons - M_{eff} is given in the Table 1. For the most part of elements both deformation potential and lattice distortions could not significantly affect the mass of free electrons M_0 i.e. $0.5 < (M_{eff} / M_0 < 2$ for **Al,Cu,Zn**, ... On the other hand **Bi, Sb** and their solutions as well as for **La** and some another elements have $M_{eff} / M_o < 0.2$ (or $M_{eff} / M_o > 5$). Some compositions as well as condition $M_o << M_{eff}$ (or $M_o >> M_{eff}$) provided high sensitivity of films to deformation.

Table 1.

Relative electron masses M_{eff} / M_0 , (M_0 - free electron mass ; M_{eff} - effective electron mass) in some metals, semiconductors and $Bi_{1-y}Sb_x$ alloies.

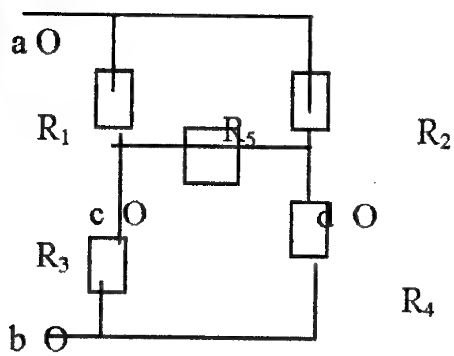
Material	M_{eff} / M_o	x - $(Bi,Sb)_{2+x}Te_{3-x}$	for M_{eff} / M_o
Cu	1.50	0.219	0.087
Ag	1,00	0.254	0.123
Zn	0.90	0.255	0.188
Al	1.60	0.260	0.310
Tl	1.15	0.261	0.251
Pb	2.10	0.273	0.218
La	4.30	0.286	0.212
Ge	1.40-:-1.20	0.288	0.213
Bi_2Te_3	0.028 -:- 0.33	0.330	0.228

Impurity of **La**, and similar the number of elements, are exist in typical of HS-CFMs They can be measured by X - ray fluorescence spectrometer,

It has been known [8] that resistance, R_{eff} of HS-CFM is simulated by lattice at the corners of which randomly located resistances - R_i ($i = 1,2,3,\dots, M$; M-total number of grains of HS-CFMs*)*. R_i is resistance of the grains of the HS-CFMs randomly connected with neighboring grains. In that model lattice one may find a simple module in Fig.2a. Model lattice consists of L modules, of this kind, each having index - k, ($k = 1,2,\dots , L$).

At the equilibium state the effective resistance - R_{eff} [a-b] (measured from a to b points) of such module is independent on the quantity of resistance R_5 = R[c-d], intervening between the c and d points (Fig.2 a; b; c; d).

$$R_{eff} = R_\alpha * (1 + R_5 / R_\beta) / (1 + R_5 / R_\gamma)$$



Where

$$R_\alpha = [R_1 * R_2 / (R_1 + R_2) + R_3 * R_4 / (R_3 + R_4)]\ ,$$

$$R_\beta = [R_1 * R_3 / (R_1 + R_3) + R_2 * R_4 / (R_2 + R_4)],$$

$$R_\gamma = [(R_1 + R_2) * (R_3 + R_4) + (R_1 + R_2 + R_3 + R_4)],$$

Fig 2 a) R_{eff}

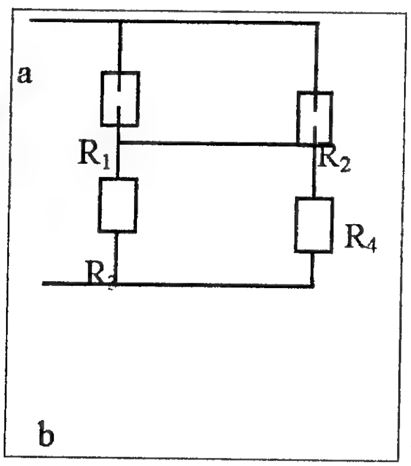


Fig.2 b) R_α

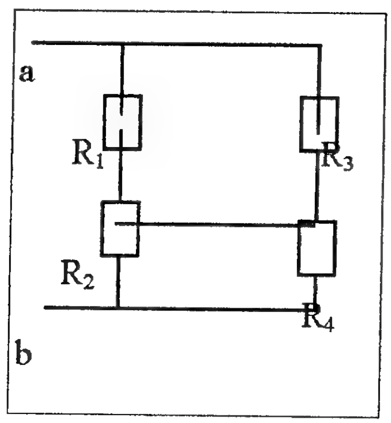


Fig.2 c) R_β

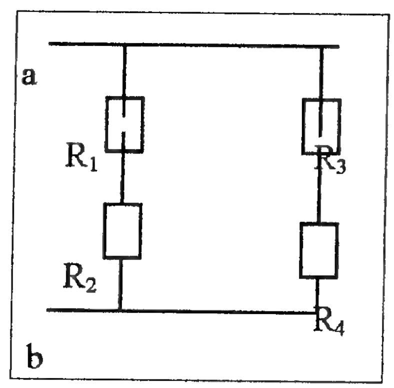


Fig. 2 d) R_γ

So

$$R_5 / R_\beta - R_5 / R_\gamma = R_5 * (R_1 * R_4 - R_2 * R_3)^\wedge 2 / [(R_1 + R_2) * (R_3 + R_4) * F],$$

$$F = R_1 * R_3 * (R_2 + R_4) + R_2 * R_4 * (R_1 + R_3).$$

The equilibrium situation is $R_\beta = R_\gamma$. In this case the electric potential in point **c** and point **d** are the same. The electric balance is disturbed ($R_\beta < R_\gamma$; $R_{eff} > R_\alpha$) under loading cycle (irreversible) of deformation. So, R_{eff} varies according to quantity of R_5.Nonelastic deformation of granules accounts for irreversible change of effective resistance R_{eff} of the HSCFMs [2]. It is the simplest model of high sensitivity of HS-CFMs

III. Stimulus elements

HS-CFMs have an intricate electrical potential relief. So there are many couples of points possesing the same electrical potential.The certain regions of HS-CFMs containing couples mentional above are active. They form the irreversible changes R_{eff} of HS-CFMs (Fig.2).

An enormal array of different electronic compositions are generated in single HS-CFM installed on the operating aviation design. One can fix irreversible changes of electronic compositions having taken sequence measurements of HS-CFMs the electic resistance at equal number of superimposed deformation intervals [1].

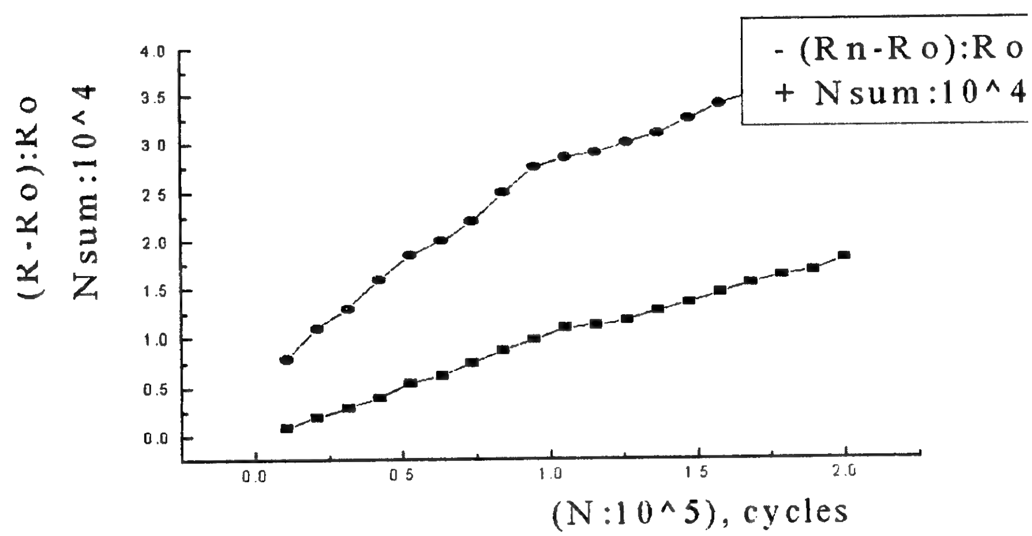


Fig. 3 HS-CFM resistance [$(R_n - R_o) / R_o$] and total acoustic emission N_{sum} of the D-16T spesimen versus number of cycles N of the superimposed deformation

corresponding to a 25 kg/ mm^2 load. The asymmetry coefficient is unity (m =1). The HS-CFMs as well as D-16T specimens are sensitive to cracking.

Both, the growth number of superimposed cycles as well as random deformation have a result an "agitation" of electronic compositions of HS-CFMs. Such"agitation" accompanies with loss of the energy deformation and leads to irreversible change of the previous electronic configuration.So for HS-CFMs the new factor appears - "history" of a sequence electronic compositions. In other words the HS-CFMs have new factor - historical dimention. A fracture dynamic of HS-CFMs requires the sequence measurements of R_n (**n** - is the number of a measurement).

In [1,6] it was found, that the variations of R_{eff} correspond to N_{sum} - number acoustic emission originated in aviation design material (Fig.3). In this paper the superimposed deformation and allied HS-CFM's microstructure are the stimulus element (SE) of set **S**.

The response of HS-CFM (for example, irreversible change of its electrical resistance R = R(**S**|**C**)) depends on separate SEs, making set **S**. The part of SEs can be subject of the experimental control, and an other part can be constant or casually changed. The active subset **C** of SEs of set **S** forms variability of effective resistance HS-CFM at superimposing of chaotic deformation.

IY. Uncrossing subset A and B

In general, SEs change of a subset **C** results in the irreversible change R - response of HS-CFM on superimposed deformation. R - function, determined on the set **S** and satisfying with additivity condition. For example, R=R(**S**|**S**) - resistance of HS-CFM, in which all stimulus elements of set **S** - are active: the crossing of subset **C** and set **S** gives the set **S** [$\mathbf{C}\cap\mathbf{S} = \mathbf{S}$]. R(**S**|**0**) - resistance of HS-CFM in which active SE is not present. R(**A**|(**A**∩**C**)) and R(**B**|(**B**∩**C**)) - resistance are assosiated with two uncrossing subsets **A** and **B** (crossing $\mathbf{A}\cap\mathbf{B} = \mathbf{0}$) of the set **S**. In general both R(**A**|(**A**∩**C**)) and R(**B**|(**B**∩**C**)) may be positive as well as negative.

Using the experimental data it is established, that after each damage process all stimulus elements of a subset **A** become active, and all stimulus elements of a subset **B** on the contrary become non active. This situation is discussed just below.

Let **X** - time to be the time in cycles of loading : **X** = 0, 1, 2, ... , and this value is not proportional to chronological time. Let **Y** - time to be chronological time measured in hours, days, etc., so **Y** = 1, 2, 3, ... in corresponding units of time. If loading cycles duration varies at random as it occurs, for example, at the aircraft flights, it is desirable to be able to convert damages accumulation in **X** - time inyo the average number of damages accumulation in **Y** - time and inversely. It can be done with the help of "time-transmission" function **Y = G(X)** [7].

Let us, **n** is a number of superimposed deformation, **n** - may be a number of cycles, or **n** - may be a number of minutes (seconds) and so on. Before **n+1** deformation is superimposed we have the next situation:

* **S** - is a set of all SEs;

* $\mathbf{C}$ - is a subset of active SEs from set $\mathbf{S}$ (before $\mathbf{n+1}$);
* $\mathbf{A}$ - is a subset containing both active as well as non active SEs from set $\mathbf{S}$;
* $\mathbf{B}$ - is another subset, containing both active as well as non active SEs from set $\mathbf{S}$;
* subset $\mathbf{A}$ and subset $\mathbf{B}$ are uncrossing;
* $\mathbf{A \cap C}$ - is a subset of active SEs from subset $\mathbf{A}$;
* $\mathbf{B \cap C}$ - is a subset of active SEs from subset $\mathbf{B}$;
* $R_n = R(S|C)$ - electrical resistance of HS-CFM after **n** superimposed deformation;
* $r_n = R(S|C) / R(S|S) = R(A|(A\cap C)) / R(A|A) = R(B|(B\cap C)) / R(B|B)$.

After **n+ 1** superimposed deformation subset **C** changes and we have the next situation:

* $\mathbf{S}$ - is a set of all SEs;
* $(\mathbf{C} + \mathbf{dC})$ - is a subset of active SEs from set $\mathbf{S}$;
* $\mathbf{A_n \cap (C + dC) = A_n}$ - all SEs of subset $\mathbf{A_n}$ become active (index **n** in sabset **A** indicated on to previous measurement);
* $\mathbf{B_n \cap (C + dC) = 0}$ - all SEs of subset $\mathbf{B_n}$ become non active;
* $R_{n+1} = R(S|(C+dC))$ - electrical resistance of HS-CFM after **n+1** superimposed deformation;
* $r_{n+1} = R(S|(C+dC)) / R(S|S)$

After **(n+1)** superimposed deformation the resistivity of HS-CFM changes:

$$R(S|(C+dC)) - R(S|C) = [R(A|A) - R(A|(A\cap C))] - R(B|(B\cap C)),$$

or

$$r_{n+1} = r_n * (1 - [R(A|A)+R(B|B)]/R(S|S)) + R(A|A)/ R(S|S).$$

Finally, one can receive

$$R_{n+1} = B_n * R_n + (1 - B_n) * \cdot M_n = Q_n^i * R_n \quad \textbf{(1)}$$

where

$$B_n = (R(S|S) - R(A|A) - R(B|B)) / R(S|S),$$
$$M_n = R(S|S) * (R(A|A) / [R(A|A) + R(B|B)]),$$

Q_n^i - is the loading operator transforming R_n to R_{n+1}, and i is a complicated symbol describing amplitude and degree of load asymmetry. The k-fold application of the simple loading operator Q_n^i transforms the resistance $R_n(i)$ into $R_{n+k}(i)$:

$$R_{n+k}(i) = B_n^k * R_n(i) + (1 - B_n^k) * M_n \quad \textbf{(2)}$$

For two operators Q_{n1} and Q_{n2} corresponding to loading modes with parameters B_{n1}, M_{n1} and B_{n2}, M_{n2}, respectively, the relationship

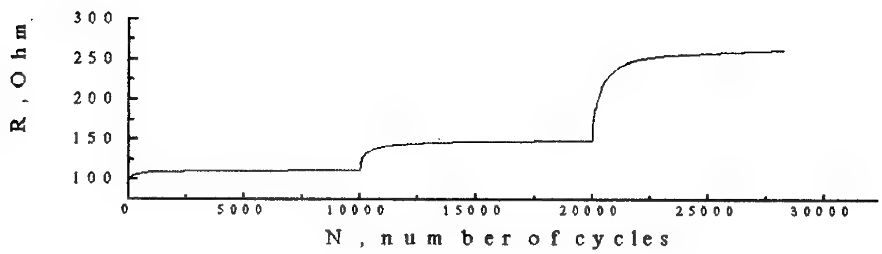


Figure 4 . Complicated mode of loading.

$R_{n+2} = Q_{n2}R_{n+1} = Q_{n2} *(Q_{n1}R_n) = B_{n1}*B_{n2}*R_n + (1 - B_{n1}* B_{n2})* M_{n1,n2}$

takes place [2] , where

$M_{n1,n1} = \{ B_{n1}* (1 - B_{n2})*M_{n2} + (1 - B_{n1}) * M_{n1} \} / [1 - B_{n1}* B_{n2}].$

Figure 4 shows the dependence of R_n for complicated modes of loading. We select R(**S**|**S**) being the same for all HS-CFM researched. R(**A**|**A**), and (**B**|**B**) might be changed with number growth. B_n and M_n are associated with couple subsets **A** and **B**. It turns out, that for regular cyclic loadings B_n as well as M_n are constants .For chaotic loadings M_n and B_n features are discussed below.

Y. Bi_2Te_3 - Sb_2Te_3 films as a HS-CFM for cumulative damage gage.

Films obtained by evaporated of **Bi_2Te_3 - Sb_2Te_3** onto poliamide substrates were studied. The films had variable volume contents of initial components. As mentioned above for **Bi, Sb** and their solutions $M_{eff} / M_o < 0.2$ takes place. So they might be used for CFDG creating. Some compositions provided high sensitivity to deformation [1].

When superimposing deformation, the film state changes. There are two ways to describe it [1] :

a) to derive physical and mathematical models of the system reaction; to find factors governing the behaviour of the parameter to be measured;
b) based on the experimental data, to derive a "time series" (survival data) consisting of a **n** terms. Analysing the series, one establish their phase dimensionality and carrying out an adaptive prediction of the parameters composing a numerical value of the **(n+1)**th term of the "ime series". Then, based on **(n+1)** terms of series, predict a numerical value of the **(n+2)**th term of the series, and so on. A complicated semiconductor film system is being monitored.

Method (a) is appropriate for simple 1-D model films. Method (b) is preferable for multidimentional real film, such as semiconductor mixture films.

The time series consisted of effective resistances $R_{eff,n}$ of the films measured in the equal number **n** of cycles of a superimposed deformation:

$$R_{No} = Ro; \quad R_{No+n} = R_{N1} = R_1;$$
$$R_{No+2 \cdot *n} = R_{N2} = R_2 \; ; \ldots.$$
$$R_{No+i*n} = R_{Ni} = R_i \; ; \ldots ; \quad N_i = N_0 + \mathbf{n*i}$$

i = 1,2,.....; No - initial number of cycles of superimposed deformation.

Linearity of loading operator (Q_n) - allows ones to calculate a reaction of film resistance on spectrum of random deformation. As an example, we consider such situation when both Q_{n1} and Q_{n2} occurs with the p_1 and p_2 probability. For the weighted mean of effective resistance - $<R_{eff}>$ we have.

$$<R_{eff}> = p_1*Q_{n1}*R_o + p_2*Q_{n2}*R_o = <B> * R_o + (1 - <B>) * << M >>,$$

There

$$<B> = p_1*B_{n1} + p_2*B_{n2}$$

$$<< M >> = \{ p_1 * (1 - B_{n1})*M_{n1} + p_2*(1 - B_{n2})*M_{n2} \} / \{ 1 - < B > \}$$

For operators Q_i occuring with probability p_i (i = 1, 2, 3, ..., K), the formulas

$$<< B >> = \sum_{i=1}^{K} (p_i * B_{ni}) \quad ,$$

and

$$<< M >> = \{\sum[p_i * (1 - B_{ni}) * M_{ni}]\} / \{1 - << B >>\}$$ take place.

In a like manner it is easy to receive formula for $<R_{eff}>$ associated with the Markoff process .

The characteristics (B_n and M_n) of coupled subsets **A** and **B** as well as complex dynamics of their change with growth of number of superimposed deformation cycles were determined. HS-CFM resistances R_n are measured through equidistant "time" intervals τ :

$$\{ R(T_n) \} \rightarrow R[T_0]; R[T_1]; R[T_2] ; \ldots. R[T_n]; \ldots; R[T_N] ; \quad T_{n+1} = T_n + \tau. \qquad \textbf{(3)}$$

Where n is the number of measurement, N is the maximum number of measured resistance R(S|C). This experimental data array is considered as a "time series". By using the Grassbereger and Procaccia [8] procedure, efficient phase dimensionalities K_g is calculated. K_g is integer and, in general, depends on the magnitude of the chosen interval (τ).

Taking into account the numerical value of K_g , formulas (1) for R_n), and using formulas of regression, we can find the $n*\tau$ depends of parameters B_n and M_n:

$$B_n = \frac{(\sum_{i=1}^{K_g} R_{n-i})*(\sum_{i=1}^{K_g} R_{n+1-i}) - K_g * \sum_{i=1}^{K_g}(R_{n-i} * R_{n+1-i}))}{(\sum_{i=1}^{K_g} R_{n-i})^\wedge 2 - K_g * \sum_{i=1}^{K_g}(R_{n-i})^\wedge 2} ; \qquad \textbf{(4)}$$

$$M_n = \frac{\sum_{i=1}^{K_g} R_{n+1-i} - B_n * \sum_{i=1}^{K_g} R_{n-i}}{K_g*(1-B_n)}; \qquad n > K_g > 2. \qquad \textbf{(5)}$$

The relationships

$$B_n = B_{n-1} = B_{n-2} = \dots = B_{n-Kg} ; \quad \text{and} \quad M_n = M_{n-1} = M_{n-2} = \dots = M_{n\text{-}Kg} \qquad \textbf{(6)}$$

take place. As a result R_{n+1} can be forecasted from **(1)** (See Fig.1,6; Table 2). Fig.7 shows the dependence of $(1 - B_n)*M_n = R(A_n|A_n)$ for complicated modes of Tu-154B loading.

Figure 5 shows typical spectrum of plane Tu-154 wing.

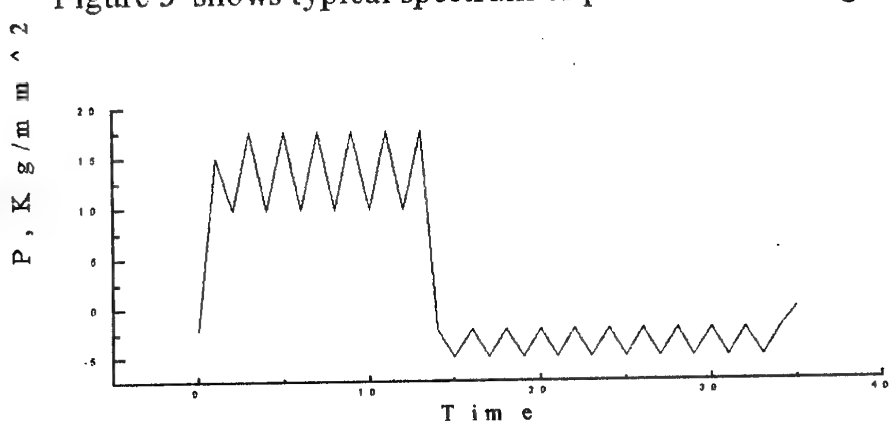


Figure 5. Typical loading spectrum of Tu-154B wing.

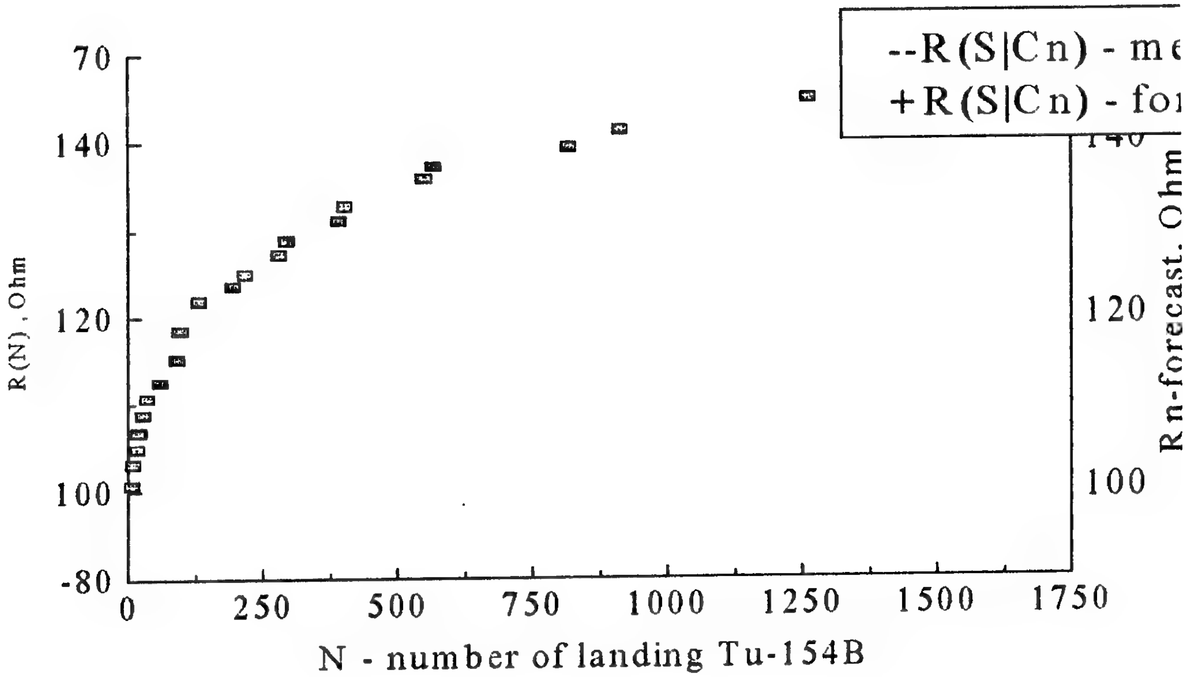


Figure 6. HS-CFMs R(**S**|**Cn**) changes for TU-154B wing loading spectra.

The $\mathbf{Bi_2Te_3}$ **-** $\mathbf{Sb_2Te_3}$ HS-CFMs were placed on to D-16T aluminium specimens and Tu-154B plane wing. Figure 3 shows the resistance R_n and total acoustic emission (A.E.- N_{sum}) from D-16T specimens versus the number of superimposed cycles [1,6]. This shows that the HS-CFMs as well as D-16T specimens are sensitive to cracking.

Figure 6 and Table 2 show the dependence of R_n for complicated modes of loading (See Fig.5). There are experimental data (-) and forecasting data (+) calculated by using the formulae (1) ,-(4,5). Applicability of formulas (1) for a load of Tu-154 plane wing is obvious.

According to the output CFDG parameters (predictors) as well as to the calibration data it is easy and reliably (with 95% trustworthy boundary) to determine N_{sum} of AE impulses (Fig. 3), generating in the constructions elements under the control, when the operation spectra of loading are over laid on it.

CFDG allows to determine the efficient number of AE impulses ($N_{sum.\ eff}$ - effective) corresponding to special deformation (m=0) loading on the construction, that is equal to operarion (including random) loading spectra.

Table 2.

n - number of measurement	N - number of landing Tu-154	R_{n+1} - measured resistance; Ohm	R_{n+1}-forecasted resistance;Ohm K_g= 3	$(1-B_n)*M_n$ = $R(A_n\|A_n)$:Ohm K_g =3
1	0	97.3		
2	2	99.2		
3	4	101.2	100.7	60.1
4	7	103.1	103.1	2.0
5	10	104.9	104.9	7.1
6	17	106.8	106.8	1.9
7	20	108.8	108.8	- 3.8
8	28	110.7	110.7	2.0
9	36	112.5	112.5	7.5
10	59	115.4	115.2	-27.4
11	90	118.3	118.5	-21.4
12	98	122.1	121.9	-14.7
13	132	123.0	123.5	40.2
14	195	126.0	124.9	44.4
15	217	126.9	127.2	23.4
16	279	129.7	128.8	29.1
17	294	130.7	131.0	18.5
18	391	133.6	132.7	17.5
19	402	135.5	135.8	-11.5
20	550	137.4	137.2	31.5
21	566	139.3	139.3	1.9
22	817	141.2	141.2	1.9
23	914	145.1	144.8	-70.7
24	1262	145.1	145.7	62.6
25	1516			

This physical criterion takes into acount real processes of damage and their relaxation in the period of rest occuring in the constraction elements at their

operating process. That differs it from the existing methods of longevity analysis, based on the calculation of periodically repeated cyclic loads at take-off and landing, as well as some setting computation algorithms.

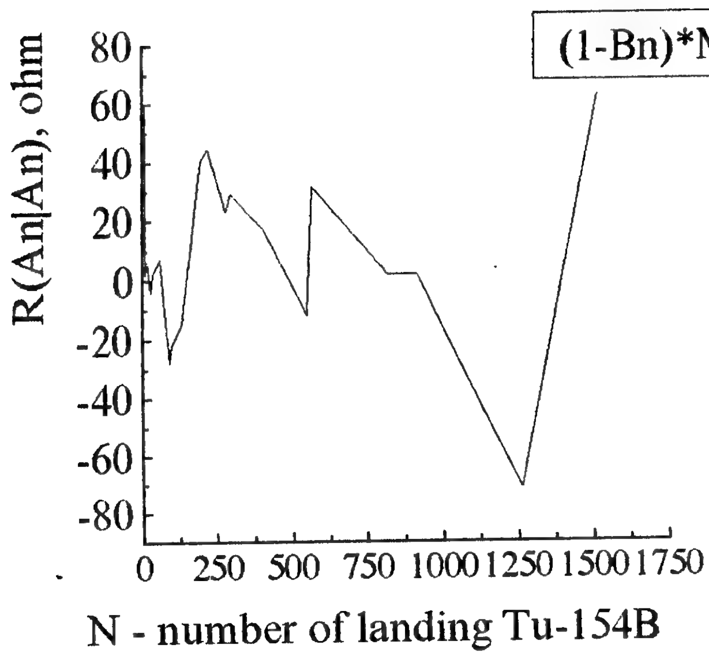


Figure 7. HS-CFMs R(**An**|**An**) changes for TU-154 wing .

Conclusion. It is necessary to put through next items for adaptive forecasting of fatigue damage of aviation designs with help HS-CFMs :

1. The HS-CFMs must be rigidly placed onto differennt elements of the aviation designs. All selected HS-CFMs have to have the same R(**S**|**S**) . The part of HS-CFMs with their resistivity R_n previously measured (See "times serious" (6)) must be calibrated. The aim of calibration is to estimate (B_n , M_n) parameters in equations (1) for simple cycles of loading with different coefficients (m) of asymmetry as well as different amplitudes and number of loading cycles. The loading of m=0 cycles and convertion of complicated blok (See fig. 5) cycles to m=0 cycles. So calibrating data can be created.
2. Equidistant "time" interval (τ) must be selected.
3. From " time series" (6) one can calculate K_g , using Grassberger Procassia [8] procedure.

4. From formulae (4) and (5) one can calculate B_n and M_n for real situations. Then using (1) one can forecast R_{n+1} for every HS-CFMs, installed on designs.
5. Then using the calibrating data one can adaptively forecast the fatigue damage of aviation designs.

I wish to thank the GosNII GA, SibNIA, US Air Force EOARD ,and the Fund of Foundamental Research of Uzbek Academy of Science for their contribution to the success of this paper.

References:

1. Shamirzaev S.,et al., Effective interface density of electron states in semiconductor mixture films. 1994// Int.J.Electronics.London,Special ussue.
2. Shamirzaev S.,et al., Conductance of heterogeneous media under superposition of irreversible random deformation. 1992//Preprint No. 172-92, PTI, Tashkent, pp.1-23.
3. Gochfeld D., Sadakov O., Plasticity and crawlibility of construction elements under repeatible loadings.1984//Moskov, "Mashinostroenie", pp.11-26.
4. Bothvina L., Damage kinetics of construction materials, 1989// Moscov, "Nauka".
5. Azimov S., Shamirzaev S., et.al., Efficient dielectric permeability of selected coverings, 1985// Geliotechnica.,pp. 31-35.
6. Sviridov V.M. , Seriouznov A.N. et al., $(Bi\text{-}Sb)_{2+x}Te_{3-x}$ heterogeneous films effective resistance under superimposing irreversible cyclic deformation., 1994// Uzbek Physic Journal, No.2,pp. 21-24.
7. Bogdanoff J., Kozin F., Probabilistic Models of Cumulative Damage,1985//John Wiley&Sons .Inc.
8. Grassberger P., Procassia I., 1983// Physica, 9D, 189-208.

II-9. Principles to predict irreversible aerospace structural characteristics under mecanical loads.

As mentioned above the Bi_2Te_3 - Sb_2Te_3 films as well as D-16T specimens are sensitive to cracking [1]. Changes of their microstructures have some common features and are fixed by continuous measurements of both the changes of the films resistivity R and summary number of acoustic impulses (N_{sum})of D-16 Aluminium. Conclusions regarding proportionality R and N_{sum} under sufficiently extensive spectrum of deformation are made.

It is necessary to put through the next items for adaptive forecasting of fatigue damage of aviation designs with HS-CFMs help :

1. The HS-CFMs must be rigidly placed onto differennt elements of the aviation designs. All selected HS-CFMs have to have the same R(**S|S**) . The part of HS-CFMs with their resistivity R_n previously measured (See "times serious" **II-6** (6)) must be calibrated. The aim of calibration is to estimate (B_n , M_n) parameters in equations (**II-8** (1)) for simple cycles of loading with different coefficients (m) of asymmetry as well as different amplitudes and number of loading cycles. The loading of m=0 cycles and convertion of complicated blok (See fig. 5 from **II-8**) cycles to m=0 cycles. So calibrating data can be created.
2. Equidistant "time" interval (τ) must be selected.
3. From " time series" (**II-8** (6)) one can calculate K_g , using Grassberger Procassia [8] procedure.
4. From formulae (**II-8** (4) and (5)) one can calculate B_n and M_n for real situations. Then using (**II-8** (1))one can forecast R_{n+1} for every HS-CFMs, installed on designs.
5. Then using the calibrating data one can adaptively forecast the fatigue damage of aviation designs.

10.Discussion of the damage mechanisms that are dictated by mixture medium response and SE performance.

Abstract of investigations are in sight.

CFDGs USING FOR INVESTIGATION OF AVIATION DESIGNS FATIGUE DAMAGE

ABSTRACT

Under superimposing irreversible random (cycle) deformation,both the effective electric resistance - R_{eff} of SE of the CFDG and the microstructure in SMs as well as a microstructure of the aviation designs materials change . The problem of the CFDGs development is to find the correlation between ΔR_{eff}[c-d] of SE and the change in microstructures . The existing procedures of analysis of durability of aircrafrt elements are based on account of loads cycle at takeoffs and landings, as well as on some known settled algorithms. The trouble with these procedures is the lacking of the physical criterion of aircraft's reliability.

Present project is aimed to establish the correlations of the SEs microstructures changes and corresponding changes of the aviation design materials microstructures at superimposing of the same spectra of irreversible random deformation on both of them.

It will be used to develop principles in order to predict irreversible aerospace structural characteristics under mechanical loads.

A change of SEs' microstructure will be investigated by using their Reff data[1] and suitable model of sets theory. A change of aviation design materials will be investigated by using

the parametrs of acoustic emission, constants of nonlinear intrinsic friction (CNIF) of aviation constructions as well as conventional methods.

It is expected to receive new knowledges about the nature of formation of effective target parameters of SE. This information will be prepared for publication and used for development of new sensitive indicators of fatique damage. As a result we hope to make mutual patent for an invention : " Gage of fatigue damage of aviation design using CFDGs"

PROJECT NARRATIVE

Contrary to the usual practice of aviation design's fatigue damage test our model makes no question of all existing materials be patchy.

Objects of research - heterogeneous semi-conductor film mixes (HS-CFM), rigidly installed on elements of aviation design. Chaostic deformation is superimposed on a design As a result an irreversible change of microstructure of HS-CFM takes place.

The feasibility of using formula (II-8 (1)) is considered. The preliminary results for spectra of load Tu-154 plane wing are shown by Uzbek Team.. **Now both U.S. and Uzbek Teams would test an effect of (1) at the variuos situations.**

The samples of HS-CFM will be calibrated against regular cycles of superimposed deformation.This will bring the calibrate tables into being. The tables will permit adaptive forecasting responce of HS-CFM on deformation.

To make scientific foundation for this table it is nessesary to investigate the parametrs of acoustic emission and (or) CNIF of aviation constructions.

The job will be performed in accordance with following 3 programms :

PROGRAMME For Uzbek Team:

1. To elaborate new canons for characterization of SEs' electron potential energy relief (EPER) changeability	Particulars contains new canons (Apr. 30, 1997)
2. The SEs' effective EPER dynamics experimental investigation	Lab findings (Jan 30, 1998)
3. The research directions of (improved films in terms of operating temperature) SE films creation.	Lab samples (Sep. 30, 1998)

PROGRAMME For U.S. Team :

1. A site of S-CMFs' installation places for researched aviation designs	A flow sheet of selection installation places (Apr. 30, 1997)
2. Experimental researches of both acoustic emission and constant of nonlinear intrinsic friction (CNIF) of aviation designs with installed CFDGs	Lab findings (Jan., 30, 1998)
3. The research of fatigue damage of aviation designs both by new and conventional methods	Lab findings (30 Jun. 1998)

PROGRAMME For mutual (U.S. and Uzbek) Teams:

1.To elaborate the lab stand for investigation of a constant of nonlinear intrinsic friction (CNIF) of aviation designs with installed CFDGs	Procedure of measurements of CNIF - (Uzbek Team - Dec.1996) Make the lab stand - (U.S. team - Mar.,1997)
2. To elicit a fact of correlations between parametrs of acoustic emission, CNIF and nonreversible change of electric resistivity of CFDG's SE installed on the aviation constructions.	Mutual Particulars contains a table of a consequantly correla tions coefficients (Dec. 1997)
3. Make mutual patent for an invention : " Gage of fatigue damage of aviation design using CFDGs "	Mutual patent pending to patent office (Jul. 30, 1998)
4. Mutual particulars	Sep., 30, 1998

Footnote :1.Both USA and Uzbek Teams will use CFDGs made pursuant to contract SPC 95-4028 (1995 - 1996).
2. Amount of CFDGs and time of its delivery will square upon mutual work.
3. Aviation designs and materials, will square upon mutual work.

Equipment to be utilized in the project. Uzbek and U.S. Teams will mainly use theirs own equipment in the project.

FACILITIES / EQUIPMENT:

In order to made measurements and investigations it is nessesary (Uzbek Team):

I) **From existing facilities or equipment** :

I.1. Build up the evaporation plant. It includes -specific equipments are made in quantity, and some standart equipments , manufactured in 1984 year.

I.2. Build up the deformation stand. It consists from mecanics set, and computer servosystem (IBM PC - 286/287 manufactured in 1989, RAM-1 Mb, hard disk - 40 Mb)

I.3. X-RAY Fluorescence spectrometer - SPECTROSCAN produced in 1993 with IBM PC

I.4. Application software

II) **Specialized equipment and material must be purchased** :

II.1. computer IBM PC-586 for estimation of effective phase dimensionality of survival data

II.2. 3-computer IBM PC - 486 for automation of time-resolved experimental procedure,process of the experimental data and presentation of the rezults in appropriare form.

II.3. strain gauge for measurements of superimposing load; vacuum gauge and vacuum pump for technology proceses ;Pt-Ro - thermocouple (15 pieces)

II.4. For measurement of electrical resistance SEs the 16-digit analog-digital converter (ADC) with internal generator of current is necessary.

Travel. To reconcile the jobs connected with teams 1,2,3 of PROGRAMME For mutual (U.S. and Uzbek) Teams it is nessesary to have for Uzbek Team members

1 scientific travel	to USA	in	1996
1 scientific travel	to USA	in	1997
1 scientific travel	to USA	in	1998

Total : 3 scientific travel to USA

4. Personel

CURRICULUM VITAE

UZBEK TEAM:

1. Shamirzaev Sezgir Khabibullaevich - Uzbek Team Co-investigator

Date and place of Birth- 24 Jun 1941, Tashkent, Uzbekistan
1958 -1964 Student of Moscow University , Moscow (Russia)
1964 - 1964 Student of Novosiberian University , Novosibirsk (Russia)
1965 - 1966 Assistance of Novosiberian University , Novosibirsk (Russia)
1966 - 1971 Engineer, Junior Scientific Researcher , Senior Scientific Researcher of Physical Technical Institute (PTI) of Academy of Sciences (AS) of Uzbekista
1971 Received a degree of candidate of Sciences (Ph.D) on Semiconductor physics
1974 - hitherto Head of laboratory of semiconductor films gages of PTI of Uzbek AS
1985 Defended doctor dissertation on semiconductor physics

S.Kh. Shamirzaev is autor and co-autor of 2 monographs, 73 papers, 7invention licences in field of Physica and Technology of Semiconductor materials and devices. He has trained 5 Ph.D. scientists. FSU defense scientist - had deal with high-frequency electronics.

Resent scientific publications :

1. S.Kh.Shamirzaev, I.V.Khamrakulov, V.M.Sviridov. Effective interface density of electron states in semiconductor mixture films.// International Journal of Electronics, Taylor & Francis Ltd, London,1994 , Special Issue.
2. Chaplygin V.N., Shamirzaev S.Kh., Ryabinov M.I., Katarushkin S.A. Use of Damage Accumulation Gauges for Taking into Account a Structure Life Expenditute.//The Fourth Russian-Chinese Scientifical Conference on the problems of aircraft strength , Novosibirsk, Russia, 25 - 30 of July 1995.
3. V.M.Sviridov,A.N.Seryoznov,I.V.Khamrakulov,D.A.Troenkin, S.Kh.Shamirzaev. Effectiv Rezistivity of (Bi,Sb)Te films, under superimposing on them irreversible rundom deformation.// Uzbekskii Phizicheskii Journal, 1994, no.2
4. Sh.A.Mirsagatov,S.Kh.Shamirzaev,M.A.Makhmudov,T.S.Shamirzaev. Effective energetic centers in ZnTe policristalline films//Uzbekskii Physicheskii Journal, 1995, no.2
5. Sh.A.Mirsagatov,S.Kh.Shamirzaev,M.A.Makhmudov,T.S.Shamirzaev.Effective intergranular electron states in polycristalline CdTe films.// Gelioteckhnica,1993,28v.
6. I.M.Daskovskii, V.M.Sviridov,V.A.Slaschov,Y.I.Ustinovschikov,S.Kh.Shamirzaev. Gage of a designs element's residual durability./ Russin Patent ,1992, No.1585722.

<u>Other participating researches</u> (Uzbek Team) :

1.Muhamediev Edhem Djikhatovich, 1962, PTI AS of Uzbekistan from 1982 , Scientist worker, Physicist, Electronic engineer;
2.Youdin Gregory Evgenievch, 1955, PTI AS of Uzbekistan from 1977, Senior scientist worker, Physicist, Computer sciences.

Both FSU defense engineers - Automatic control of thermal shock for a Big Solar Plant.

Resent scientific publications :

7-th International Symposium on Solar Thermal Concentrating Technologies. September 26-30, 1994, Moscow, Russia.

G.E.Youdin, T.T.Riskiev "Energy flux density distribution in focal volume for a Big Solar Furnace".

G.E.Youdin, T.T.Riskiev "Energy flux density shaping for a Big Solar Furnace".

E.D.Muhamadiev, G.E.Youdin, R.F.Roumi, A.A.Yakimov "Master control system of heliostat field for a Big Solar Plant".

In the frame of this project Muhamediev E.D. and Yoydin are supposed to be responsible for servise of computing enviaronment.

3.Vainerman Galina Isakovna, 1962, PTI AS of Uzbekistan from 1982, engineer,have diplom of Tomsk University (Russia 1985) - is specialist in the field of technology of Semiconductors. In the frame of this project Vainerman G.I.is supposed to be responsible for the production SEs.

4. Shamuratov Kholmat Atakulovich, 1938, PTI of Uzbekistan from 1978, defended doctor dissertation in semiconductor physics 1992 - is specialist in the field of technology of high-temperature Semiconductors. In the frame of this project Shamuratov Kh.A. is supposed to be responsible for the production high-temperature SEs.

Budget Narrative list

1. computer - Pentium - $3,000.00 for estimation of effective phase dimensionality of serurvival data
2. computer IBM PC - 486 -3* $2,000.00 = $6,000.00 for automation of time-resolved experimental procedure,process of the experimental data and presentation of the rezults in appropriare form.
3. strain gauge (William T.Bean Inc. US) for measurements of superimposing load
   vacuum gauge for technology proceses Pt-Ro - thermocouple
4. For measurement of electrical resistance SEs the 16-digit analog-digital converter (ADC) with internal generator of current is necessary.
5. Materials and Supplies (Bi,Sb,Te, Pt, In, Gd, Sc,La ; SiC substrates, fusible metals, chemical reagents).

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	5 August 1996	Final Report, July 1995 –July 1996

4. TITLE AND SUBTITLE

The Research of Structural Models of Fatigue Damage of Mixture Films.

5. FUNDING NUMBERS

F6170895W0290

6. AUTHOR(S)

Dr. S. H. Shamirzaev

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Physical-Technical Institute, Scientific
G. Mavlyanova, 2B; PTI of AS
Tashkent 700084
Uzbekistan

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES

EOARD
PSC 802 Box 14
FPO 09499-0200

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

SPC 95-4028

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

A

ABSTRACT (Maximum 200 words)

This report results from a contract tasking Physical-Technical Institute, Scientific as follows: The contractor will develop mathematical models connecting an electric resistance change of semiconductor mixture films with the number of loading cycles. Research the damage mechanisms that are dictated by the mixture medium response and sensitive element performance. Develop a fatigue damage model of semiconductor mixture films for irreversible random deformation. Develop principles to predict irreversible aerospace structural characteristics under mechanical loads.

14. SUBJECT TERMS

EOARD, Materials

15. NUMBER OF PAGES

37

16. PRICE CODE

N/A

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19, SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102